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# (54) A pressure sensor having piezo-resistive gauges

(57) A pressure sensor comprising piezo-resistive stress gauges ($R_1$, $R_2$, $R_3$, $R_4$) disposed on a deformable substrate (1) acting as a membrane separating two chambers which are connected to the pressures to be measured. The sensor is characterised in that the piezo-resistive strain gauges are obtained by precise deposition of resistive ink from an ink jet. Each pair of gauges $R_1$, $R_4$ and $R_2$, $R_3$ may be formed from a single deposited layer by a subsequent etching step.

FIG 1

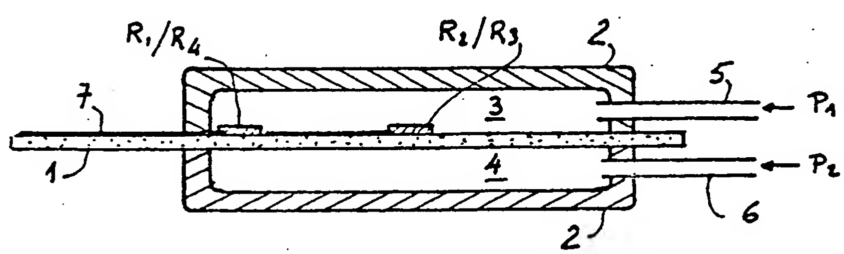

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FIG 1

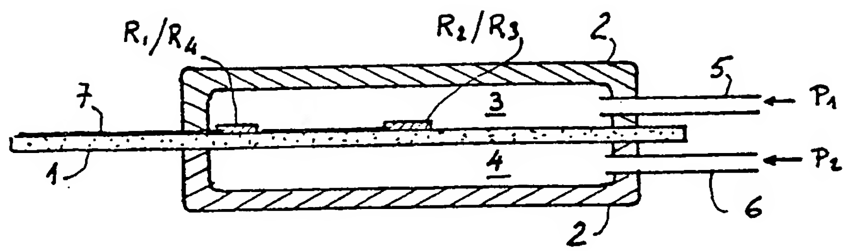



FIG 2

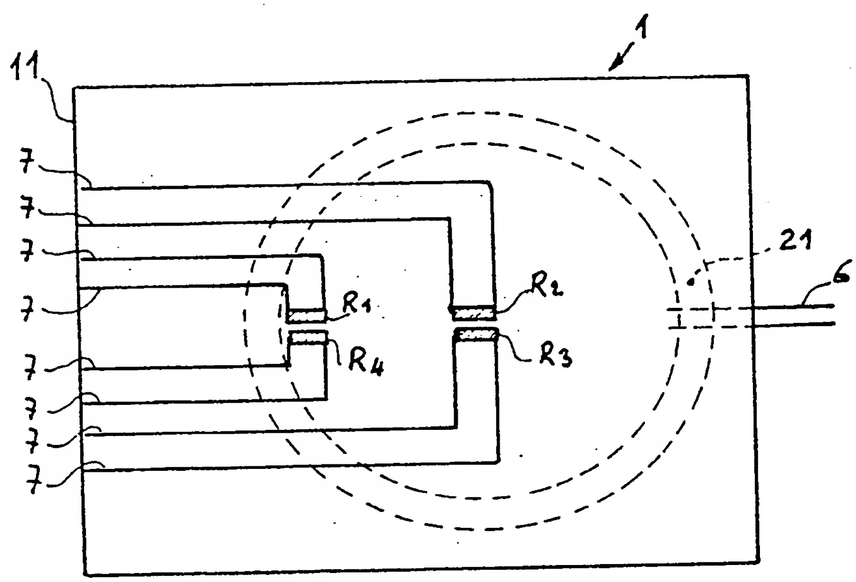



FIG 3

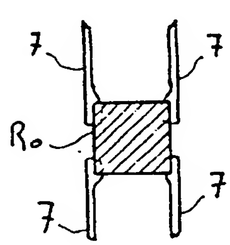
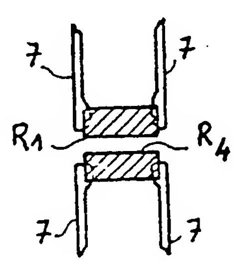



FIG 4



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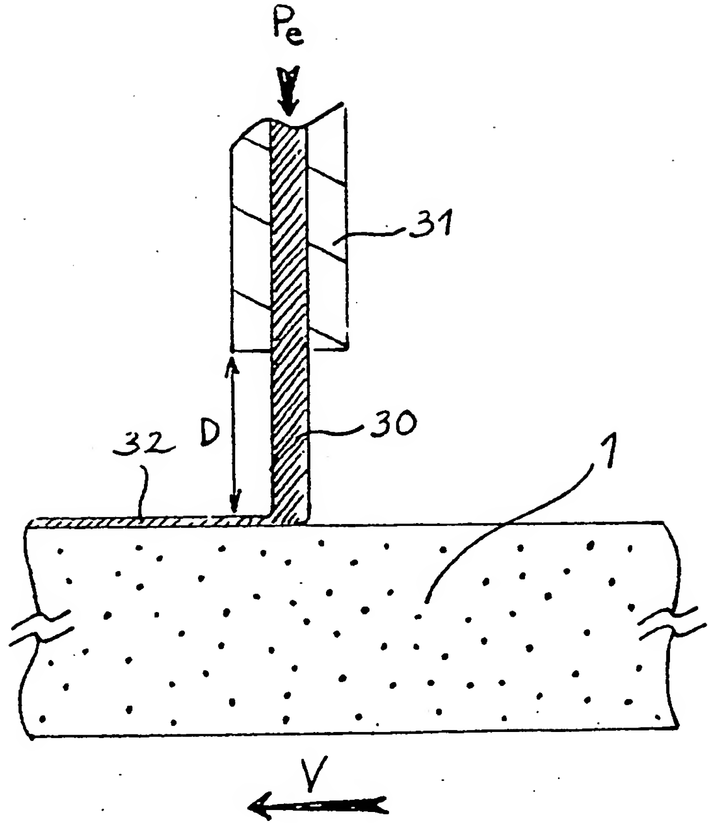


FIG 5

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DESCRIPTION

PRESSURE SENSOR HAVING PIEZO-RESISTIVE GAUGES.

The present invention relates to devices using strain gauges mounted on a deformable substrate for obtaining electrical signals which represent the deformations of said substrate. More particularly, it relates to a spressure sensor having piezo-resistive gauges.

The piezo-resistive properties of resistive inks are described in an article by Yu. A. Gusev entitled "Film strain resistor for temperatures up to 1000°C", which appeared in the Khar'kov Aviatic Institute Journal, Volume 2, March/April 1976. They are also found in an article by Holmes entitled "Changes in thick-film resistor values due to substrate flexure", which appeared in Volume 12 of the Microelectronics and Reliability Journal in 1973, and studied the influence of mechanical stresses on resistor values in thick-film microelectronics. The author proposes an extensometer having thick-film resistors on a ceramic substrate for measuring the gauge factor of these resistors which he places, according to the inks used, as being of the order of 11.

Finally, French Patent No. 70 25 084 proposes applying this knowledge to a device for measuring pressure, whose thick-film extensometers are applied to the substrate by the method of silk screen printing.

In effect, the guages are drawn on a silk screen, which is then applied to the substrate before being impregnated by a resistive ink. The mesh of this screen, woven from stainless steel wires, does not allow sharply defined, regular contours to be obtained, or an absolutely constant deposition thickness, which causes dispersion of the electrical and piezoelectric characteristics of the gauges obtained in this way.

It is an object of the present invention to eliminate those disadvantages which make it almost impossible to use such gauges to make pressure sensors which are sufficiently accurate to be applied in the fields of aeronautics and space.

To this end, the invention relates to a pressure sensor having pizeo-resistive gauges which are made using resistive inks deposited directly on a substrate by means of printing using an ink jet.

The sensor according to the invention makes it possible to measure both absolute and differential pressures wherever there are two cavities separated by the substrate, which acts as a membrane and is subjected to a resulting pressure which is equal to the difference between the pressures prevailing in the two cavities. If one of the cavities is made hermetic and sealed under vacuum, the sensor measures the absolute pressure prevailing in the other cavity.

The strains induced in the membrane (the substrate) are essentially due to the flexure thereof, at least for membrane thicknesses which are sufficiently large with respect to its surface. The distribution of these strains is such that each compression strain on the periphery of the deformable element corresponds, on the same face, to an extension strain in the centre of the element. This difference in the direction of variation of the strains, and hence of the elongations, makes it possible to use piezeo-resistive gauges to make a Wheatstone bridge, in which gauges subjected to the same strains are placed in two opposite branches.

In order to make the gauge bridge, piezo-resistive resistors are used whose gauge factor is positive for simultaneously parallel and perpendicular elongations in the direction of the current.

Such gauges are made using conductive compositions based on conductive oxide mixed with a glass matrix. This composition is in the form of an ink whose viscosity can be varied by adding different solvents, which enables it to be directly adapted to the depositing process and to use capillary tubes for the ink jet which are fine enough to obtain very precise drawing of the gauges.

The gauges are made by depositing a fine layer of desired inks. The depositing process which uses the technique of direct printing, makes it possible to use a defined geometry to obtain a corresponding drawing on the membrane without recourse to masking processes of any kind. Several passes are necessary to make a gauge bridge. In fact, it is first necessary to deposit an ink of a conductive type to make the conductors, then an ink whose composition corresponds to the piezeo-resistive resistors which are connected to the previously deposited conductors. The process used allows a large variety of geometries to be made simply by modifying the path of the depositing capillary tubes, programmed from the specification of the structure of the sensor.

After each deposition of ink, there is a baking operation to eliminate the solvents contained in the composition and to form the connection between the particles of conductive oxide and the glass matrix. This operation, which is carried out at high temperature, produces stability of the resistors.

At the end of the deposit of the gauges of the measuring bridge, the same process can be used to apply a layer of glass to the whole of the membrane using an ink or paste, particularly a glass-based one.

This layer of glass is used on the one hand for the sealing operation on the edge of the membrane, which creates the cavities and, on the other hand, to improve the air-tightness of the cavities following sealing. The materials which make up the membrane may in fact have a certain porosity, which will be inhibited by said layer. The glass deposited in this way also acts to protect the deposited gauges against contamination during the sealing operation and with respect to the fluids to which the membrane is exposed during the operation of the sensor.

Such a process can be applied to ceramic diaphragms, in particular to the alumina type, which has good mechanical properties, although it is possible to envisage other types of substrate made, for example, from glass, silica or enamelled metals, depending on the application in question.

Another characteristic of the invention relates to the manner of obtaining two pairs of gauges which may be connected electrically in a balanced Wheatstone bridge. To do this, after depositing four pairs of conductive elements on the membrane, two pairs being disposed on each of the two locations provided for the pairs of gauges, a piezo-resistive element is deposited on each group of two pairs of conductors, which element is calibrated as a function of the ohmic

values desired, such that it is simultaneously in electrical contact with each of the four conductors. Each element is subsequently divided by etching into two substantially identical gauges which are electrically insulated from one another.

The etching, which can be carried out by a jet of abrasive powder or by means of a laser beam, may be guided in the course of the operation under the control of the value of the resistors between four conductors, in order to guide the path of the etching device and thus to control the value of the two resistors obtained from each element.

The two resistors resulting from this operation have very close electrical and piezo-resistive characteristics, because they are obtained using a single element. This is particularly important for limiting the temperature drifts of the Wheatstone bridge, which are due to differences between the drift coefficients of the resistors making up the bridge. It has been observed that resistors whose values are very close to a given temperature have temperature drifts which are also very close. Thus, if the resistors of the bridge are such that the unbalance at the output is less than 1% of the serviceable voltage, the drift of the bridge will be able to be less than $1\mu V/ V/^{\circ}C$, which leads to a stability of the measuring cell of 200 ppm/$^{\circ}$C before any compensation.

Thanks to this method, the position of the gauges relative to the embedding of the membranem is also extremely precise.

The accompanying drawings illustrate, by way of example only, a method of making a pressure sensor according to the invention. In the drawings:

Fig.1 is a cutaway view of a sensor;

Fig.2 is a plan view of the sensor in Fig.1;

Figs. 3 and 4 show the piezeo-resistive elements of the sensor in Fig.1 before and after etching; and

Fig.5 is a partial cutaway view of a piezo-resistive element of the sensor in Fig.1 during its making by means of direct printing using an ink jet.

As shown in the drawings, the pressure sensor comprises a substrate 1, for example made of ceramics, which is sandwiched between two circular dishes 2 also made of ceramics and sealed onto the substrate by means of a specific glass-based ink, which has previously been deposited on circular embedding zones 21, represented by dotted lines in Fig.2.

The dishes 2 have an appropriate form for defining two distinct cavities 3 and 4 on either side of the substrate.

Two tubes 5, 6, which are sealed in each of the dishes 2, allow the cavities 3 and 4 to receive pressures P1 and P2 respectively, in the case of a

differential pressure sensor. It is the substrate 1 which acts as the deformable membrane, and two pairs of piezo-resistive gauges, on the one hand R1 and R4, and, on the other hand, R2 and R3, are mounted on this substrate 1 to obtain on the electrical conductors 7, with which the piezeo-resistive gauges R1, R2, R3 and R4 are in contact, electrical signals representing the deformations of the substrate 1. In this case, for example, the pair R2, R3 is disposed in the centre of the zone acting as the circular membrane and the other pair R1, R4 is disposed close to the embedding zone 21, as shown in Figs. 1 and 2.

The electrical conductors 7 are made using conductive ink and each end at the same edge 11 of the substrate to facilitate electric power supplies.

The process of making the gauges R1, R2, R3 and R4, as well as, in this case, the conductors 7 and the layers of glass-based ink, will be described below with reference to Fig.5. The process involved is a process of direct printing by way of a jet of ink. This ink jet 30 is produced at the outlet of a capillary tube 31, which forms a nozzle and is connected to an ink reservoir (not shown in Fig.5) under a raised pressure Pe. In this Figure, part of the tube 31 is shown, its end being disposed at a distance D from the substrate 1. The tube 31 is

perpendicular to the surface of the substrate 1, on which the ink is to be deposited. As soon as the ink jet 30 is formed under the action of the pressure Pe, the substrate 1 is moved so that it is displaced relative to the tube 31 at a controlled speed V so that a strip 32 of a suitable thickness and width is deposited.

By way of example, using an ink whose viscosity is 150 centipoises, a tube 31, whose internal diameter is 100μ, disposed at a distance D, which is less than or equal to 500μ, and a relative rate of displacement V or 5 cm/s, a strip 32 is deposited which has a thickness which is substantially equal to 10μ and a width which is substantially equal to 125μ, the difference between the width of the strip 32 and the diameter of the jet 30 being due more to the surface tension forces in play as soon as the ink comes into contact with the substrate 1, than to a spreading of the jet 30 at the outlet of the tube 31.

The pressure Pe at which the ink is propelled out of the reservoir is obtained using a compressed gas, for example air or nitrogen, under a pressure which is between approximately 1 bar and approximately 10 bar. The jet 30 is interrupted suddenly by putting the ink reservoir under a vacuum.

Using tubes whose diameter is between approximately 60µ and approximately 300µ, and a system of relative positioning of the substrate 1 with respect to the tube 31, whose precision is of the order of 1µ, it is possible to deposit gauges at high speed, the precision of the contours of which gauges being of the order of 5µ.

With such precision, there is no need to repeat or adjust, as is necessary in the processes known from the prior art.

In order to make each of the pairs of gauges R1, R4 and R2, R3, a single element, represented by Ro in Fig.3, and being in the form of a substantially square block, is deposited to cover four condutors 7, which have been deposited previously. This element is then etched by a jet of abrasive powder or by a laser beam to obtain the pair of resistive gauges R1 and R4, for example, as shown in Fig.4.

In the case of a differential sensor, where the two faces of the substrate are exposed to liquids under pressure, which may be corrosive, the resistors are protected by depositing on the two faces of the substrate the material of a sealing layer of glass, instead of restricting it to the zone 21 on each face. Furthermore, this protection improves the stability of the resistive gauges of such a sensor.

The invention lends itself particularly well to making pressure sensors which are reliable and have a high degree of accuracy, which enables them to be used particularly in the fields of aeronautics and space.

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CLAIMS

1. A pressure sensor having piezeo-resistive gauges mounted on a deformable substrate for obtaining electrical signals on conductors, which signals represent deformations of said substrate, the gauges being fabricated using resistive inks deposited directly on the substrate by direct printing using an ink jet.

2. A pressure sensor as claimed in claim 1, wherein the ink jet is produced at the outlet of a capillary tube, whose end is disposed at a distance from said substrate, while there is relative displacement between the substrate and said capillary tube.

3. A pressure sensor as claimed in claim 1 or 2, wherein the ink jet is obtained by propelling the ink out of a reservoir using a compressed gas.

4. A pressure sensor as claimed in any of claims 1 to 3, comprising two pairs of gauges, each obtained using a single element in contact with four conductors, which element is subsequently etched to obtain two distinct, electrically isolated and identical gauges.

5. A presure sensor as claimed in claim 4, wherein the etching is effected by means of a guided laser beam.

6. A sensor as claimed in any of claims 1 to 5, wherein, when the conductors and the calibrated gauges have been deposited, the entire substrate is covered by a protective layer made using a glass-based ink by means of direct printing using an ink jet.

7. A pressure sensor substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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